IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Japanese Patent Application of
Shinichi NISHIDA et al.

Japanese Patent Application Nos. 286642/1996, 029032/1997

Filing Date: October 29, 1996, February 13, 1997

for: "ACTIVE MATRIX LIQUID CRYSTAL DISPLAY PANEL"

VERIFICATION OF TRANSLATION

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(1) that I know well both the Japanese and English languages;

(2) that I translated the above-identified Japanese Patent Application from Japanese to English;

(3) that the attached English translation is a true and correct translation of the above-identified Japanese Patent Application to the best of my knowledge and belief; and

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March 7, 2001
Date

Hiroo Otsu
Hiroo OTSU

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of

Shinichi NISHIDA, et al.

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For: ACTIVE MATRIX LIQUID CRYSTAL DISPLAY PANEL

SUBMISSION OF CERTIFIED ENGLISH LANGUAGE TRANSLATIONS OF APPLICANTS'PRIORITY DOCUMENTS

Commissioner of Patents
Washington, D.C.

Sir:

Applicants hereby submit certified English language translations of Applicants'Priority documents - Japanese Patent Application Nos. 386642/1996 and 029032/1997.

Respectfully submitted,

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(English Translation of JP 08-286642P)
DOCUMENT NAME SPECIFICATION

TITLE OF INVENTION

ACTIVE MATRIX LIQUID CRYSTAL DISPLAY PANEL

CLAIMS

1. An active matrix liquid crystal display panel, comprising:

a first substrate on which a plurality of color layers having transmission wavelengths different from each other are provided in parallel to each other;

a second substrate disposed in an opposing relationship to said first substrate with a predetermined clearance left from said first substrate for generating a predetermined electric field when a predetermined voltage is applied; and

a liquid crystal layer formed from liquid crystal injected in a gap defined by a surface of said first substrate adjacent said second substrate and a surface of said second substrate adjacent said first substrate;

the electric field generated by said second substrate being substantially parallel to said liquid crystal layer to control a display;

characterized in that

said liquid crystal layer having a thickness which varies depending upon the transmission wavelengths of said color layers.

2. An active matrix liquid crystal display panel as claimed in claim 1, characterized in that said liquid crystal layer has a thickness which increases in proportion to one wavelength selected from a wavelength region in which transmission factors of said color layers are higher than 70 % those at peaks of transmission spectra of said color layers.

3. An active matrix liquid crystal display panel as claimed in claim 1 or 2, characterized in that

said second substrate includes

a plurality of pixel electrodes provided corresponding to said color layers, the predetermined voltage being applied to said pixel electrodes, and

a plurality of opposing electrodes provided in parallel to said pixel electrodes for each of said color layers for cooperating, when the voltage is applied to said pixel electrodes, with said pixel electrodes to generate the electric field therebetween,

said pixel electrodes and said opposing electrodes being spaced from each other by distances which are different for the individual color layers.

4. An active matrix liquid crystal display panel as claimed in claim 3, wherein said first substrate has a protective layer provided on a surface thereof adjacent said second substrate for preventing elusion of impurities from said color layers.

DETAILED EXPLANATION OF THE INVENTION

[Technical field to which the invention pertains]

This invention relates to an active matrix liquid crystal display panel of the structure wherein liquid crystal is held between transparent insulating substrates.

[Prior art]

An active matrix liquid crystal display panel (hereinafter referred to as AMLCD) wherein a thin film field effect transistor (hereinafter referred to as TFT) is used as a switching element for a pixel has a high picture quality and is utilized widely as a display device for a portable computer or a monitor for a desk top computer of the space saving type.

In recent years, in order to achieve a high quality of a liquid crystal display, a display method called in-plane switching mode which makes use of a transverse electric field in order to improve the visibility angle characteristic has been proposed (for example, Asia Display `95) (Prior Art 1).

According to the display method, a pixel electrode and an opposing electrode are formed in parallel to each other, and a voltage is applied between the pixel electrode and the opposing electrode to form a parallel electric field in a plane of a liquid crystal layer to vary the direction of the director of the liquid crystal thereby to control the amount of transmission light therethrough.

In the liquid crystal display system described above, since the director moves only in a direction substantially parallel to and in the plane of the liquid crystal layer, such

a problem that, as the director rises out of the plane of the liquid crystal layer as in the TN (Twisted Nematic) mode, the relationship between the transmission light amount and the applied voltage exhibits a large difference whether the liquid crystal layer is viewed from the direction of the director or from the direction of a normal to the liquid crystal layer does not occur, and a display image which looks in a similar manner from whichever direction it is viewed can be obtained over a very wide visual angle.

FIG. 9 is a view showing a liquid crystal display system which is driven by a transverse electric field and exhibits a good display characteristic.

For the display system described above, several systems have been proposed depending upon the initial orientation condition of the liquid crystal layer and the manner of setting of polarizing plates. Of those systems, such a system as shown in FIG.9, wherein a liquid layer is injected in the same direction on both substrates and, in the initial orientation condition, the directors are oriented uniformly in this direction while one of two polarizing plates between which the substrates are held and which form a cross nicol is oriented to the direction of the directors in the initial condition so that, when no voltage is applied, a black display is obtained, but when a voltage is applied, the directions of the directors are turned to obtain a white display, is considered advantageous in that the black level can stable be made low.

In the display mode of the display system described above, the transmission factor T of light coming in from the front is given in accordance with the turning angle ϕ of the directors based on the following expression:

$$T = \sin^2(2\Phi) \cdot \sin^2(\pi \cdot \Delta n d_{eff}/\lambda) \qquad (1)$$

where d_{eff} is the effective value of the liquid crystal layer thickness which undergoes turning deformation when the liquid crystal directors are twist deformed while they are large at a central portion and are fixed at interfaces of the liquid crystal with the substrates, and is smaller than the actual liquid crystal layer thickness.

It has been experimentally confirmed that, for example, where a liquid crystal cell of 4.5 μm thick is formed and liquid crystal having a dielectric constant anisotropy $\Delta n = 0.067$ is injected in the liquid crystal cell, if a transverse electric field is applied so as to induce a deformation corresponding to $\phi = 45$ degrees, the transmission factor exhibits a wavelength dependency as seen from the expression (1) and has a maximum value substantially at $\lambda = 550$ nm. Conversely, from this, it is esteemed that $d_{eff} = 4.1\ \mu$m using the expression (1), and the transmission factor for any other wavelength substantially coincides with a value obtained by substituting $d_{eff} = 4.1\ \mu$m into the expression (1).

In this instance, between the representative wavelength 460 nm selected by a color filter of blue and the

representative wavelength 610 nm selected by another color filter of red, the transmission factor given by the expression (1) varies within a range less than 10 % the highest value thereof. However, even if a special process is not performed, a significantly coloring image does not look when the liquid crystal cell is viewed from the front. Where a higher color purity is required, transmission lights from the color filters of R, G and B can be balanced well by adjusting the transmission factors of the color filters or the spectrum of back light.

It is examined here that, when a transverse electric field is applied to turn the directors approximately by 45 degrees to provide a white display, a substrate is viewed obliquely from a direction perpendicular to the turned directors.

FIGS. 10(a),(b) are views illustrating transmission of light through liquid crystal when it comes in obliquely, and wherein (a) is a view as viewed from an oblique direction with respect to a substrate and (b) is a view as viewed from a parallel direction to the substrate.

While the transmission factor of light passing obliquely through a liquid crystal cell is not precisely represented by the expression (1), it is essentially same in that the light passes through a cross nicol as a retardation is produced between an ordinary ray and an extraordinary ray when it passes through the liquid crystal. Accordingly,

$$f = \sin^2(\pi \cdot \Phi nL/\lambda) \qquad (2)$$

wherein d_{eff} of the second factor of the right side of the expression (1) is replaced with the optical path length

L when a ray passes through the effectively turned liquid crystal layer, makes an important factor which dominates the intensity of the transmission light.

When the liquid crystal cell is viewed from the front, with green light corresponding to λ = 550 nm, the transmission factor spectrum has a maximum value, and consequently,

$$\pi \cdot \Delta nd_{eff}/\lambda = \pi/2 \qquad (3)$$

and the factor f in expression (2) is 1.

As seen from FIGS. 10, when the liquid crystal cell is viewed from a direction which is perpendicular to the directors and oblique to the substrate, the refractive index anisotropy Δn felt with transmission light is the difference in length between the major axis and the minor axis of an ellipse which corresponds to a section of a refractive index ellipsoid of revolution having a major axis in the direction of the directors of the liquid crystal when the refractive index ellipsoid of revolution is cut along a wave front of the ray. In this instance, since the wave front includes the major axis of the ellipsoid of revolution, the refractive index anisotropy Δn felt with the light is fixed irrespective of the inclination angle θ from the direction of a normal to the substrate. Accordingly, as the inclination angle θ increases, $\pi \cdot \Delta nL/\lambda$ gradually increases from $\pi/2$, while the factor f given by the expression (2) decreases and, reflecting

this, also the transmission factor T decreases.

With light of red corresponding to λ = 610 nm,

$$\pi \cdot \Delta nd_{eff}/\lambda < \pi/2 \qquad (4)$$

on the front, and the factor f is smaller than 1. From the same reason as in the case of λ = 550 nm, as θ increases, $\pi \cdot \Delta nL/\lambda$ increases, and after it becomes equal to $\pi/2$, it further increases exceeding $\pi/2$. In response to the increase, also the factor f becomes equal to 1 once, and thereafter decrease gradually. Consequently, also the transmission factor T reflects this and increases once and then decreases gradually.

On the other hand, with light of blue corresponding to λ = 460 nm,

$$\pi \cdot \Delta nd_{eff}/\lambda > \pi/2 \qquad (5)$$

on the front, and the factor f is smaller than 1. From the same reason as in the case of λ = 550 nm, as θ increases, $\pi \cdot \Delta nL/\lambda$ increases and is spaced farther from $\pi/2$. Consequently, f decreases farther from 1. Since the rate of increase of f when the optical path length L increases is given by

$$\delta f/\delta L = (\pi \cdot \Delta n/\lambda) \cdot \sin(2\pi \cdot \Delta nL/\lambda) \qquad (6)$$

as $\pi \cdot \Delta nL/\lambda$ increases exceeding $\pi/2$, f decreases suddenly. Accordingly, it can be said that the decrease of f where λ

λ = 460 nm is more sudden than that when λ = 550 nm, and also the transmission factor T decreases suddenly.

From the foregoing, since, as θ increases, blue light decreases most suddenly and green light decreases comparatively moderately whereas red light first increases and then decreases, although white light looks on the front, as θ increases, the light gradually appears coloring with red.

This can be confirmed more quantitatively by a simulation which is performed taking a deformation and an optical anisotropy of liquid crystal into consideration.

FIG. 11 is a diagram illustrating a relationship between the inclination angle and the transmission factor when, in order to display white, light comes into a substrate from a direction perpendicular to the liquid crystal directors and oblique to the substrate. It is to be noted that the axis of abscissa indicates the inclination angle θ and the axis of ordinate indicates a result of calculation of the transmission factor normalized with the transmission factor on the front.

As seen from FIG. 11, as θ increases, the transmission factor generally decreases, and above all, it can be seen that the transmission factor for blue decreases most rapidly.

FIG. 12 is a diagram illustrating a relationship between the inclination angle and the transmission factor when, in order to display white, light comes into a substrate from a

direction same as the direction of the liquid crystal directors and oblique to the substrate.

As seen in FIG. 12, when the line of sight is gradually inclined to the same direction as that of the directors in a white display, if a similar simulation is performed, it can be seen that red light conversely exhibits the most significant attenuation.

The phenomena described above occur quite similarly with an actual color liquid crystal display panel on which color filters are provided. In fact, it has been confirmed that, when a color liquid crystal panel produced in the same conditions as those of the liquid crystal cell described above is viewed from an oblique direction, it looks coloring.

As described above, with an active matrix liquid crystal display apparatus which is constructed using a transverse electric field, although a good display characteristic is obtained over an angle of visibility wider than that of a conventional TN mode, when viewed from an oblique direction, depending upon the direction, a display image looks coloring significantly. If such coloring occurs, then when image data of full colors are to be displayed, the image of the original picture is deteriorated remarkably.

On the other hand, methods of forming, in a liquid crystal display panel having color filters, liquid layers for the colors of the color filters with different layer thicknesses are disclosed in Japanese Patent Laid-Open Application No. Showa 60-159831 (Prior Art 2) and Japanese Patent Laid-Open

Application No. Showa 60-159823 (Prior Art 3). The methods propose a display system wherein liquid crystal is held between two glass substrates and a voltage is applied between transparent electrodes on the opposite sides of the liquid crystal to vary the alignment of the liquid crystal layer, above all, of a liquid crystal display apparatus of the twisted nematic (TN) mode, and besides relates to a method of optimizing the characteristic when the liquid crystal display apparatus is viewed from the front. Those methods are quite different in structure, purpose and principle from the present invention which has been made to suppress coloring which occurs upon oblique light incidence in a transverse electric field display system which has a picture quality much higher than that of the TN system as hereinafter described.

Different methods are proposed in Japanese Patent Laid-Open Application No. Heisei 1-277283 (Prior Art 4) and Japanese Patent Laid-Open Application No. Heisei 6-34777 (Prior Art 5) wherein the thickness of a liquid crystal layer is optimized for individual colors in order to improve the characteristic on the front in simple matrix driving. Similarly, however, the methods are essentially different from the present invention.

Further different techniques are proposed in Japanese Patent Laid-Open Application No. Showa 60-159827 (Prior Art 6), Japanese Patent Laid-Open Application No. Heisei 2-211423 (Prior Art 7) and Japanese Patent Laid-Open Application No. Heisei 7-104303 (Prior Art 8) wherein liquid crystal layers

are formed with different thicknesses for the colors of color filters. However, they relate to a structure and a production method proposed to optimize the front characteristic of the TN mode and are essentially different from the present invention.

[Problems that the invention is to solve]

As described above, with an active matrix liquid crystal display apparatus which is constructed using a transverse electric field, while a good display characteristic is obtained over a wider angle of visibility than that of the conventional TN system, there is a problem in that, when viewed from an oblique direction, significant coloring appears depending upon the direction, and consequently, when image data such as, for example, a photograph are to be handled, the image of the original picture is deteriorated very much.

The present invention has been made in view of the problems of the prior art described above, and it is an object of the present invention to provide an active matrix liquid crystal display apparatus of the transverse electric field driven type which has a good display characteristic free from coloring from whichever direction the display apparatus is viewed.

[Means for solving the problems]

In order to attain the objects described above, according to an aspect of the present invention, there is provided an active matrix liquid crystal display panel, comprising a first substrate on which a plurality of color layers having transmission wavelengths different from each other are

provided in parallel to each other, a second substrate disposed in an opposing relationship to the first substrate with a predetermined clearance left from the first substrate for generating a predetermined electric field when a predetermined voltage is applied, and a liquid crystal layer formed from liquid crystal injected in a gap defined by a surface of the first substrate adjacent the second substrate and a surface of the second substrate adjacent the first substrate, the electric field generated by the second substrate being substantially parallel to the liquid crystal layer to control a display, the liquid crystal layer having a thickness which varies depending upon the transmission wavelengths of the color layers.

The liquid crystal layer may have a thickness which increases in proportion to one wavelength selected from a wavelength region in which transmission factors of the color layers are higher than 70 % those at peaks of transmission spectra of the color layers.

The second substrate may include a plurality of pixel electrodes provided corresponding to the color layers, the predetermined voltage being applied to the pixel electrodes, and a plurality of opposing electrodes provided in parallel to the pixel electrodes for each of the color layers for cooperating, when the voltage is applied to the pixel electrodes, with the pixel electrodes to generate the electric field therebetween, the pixel electrodes and the opposing electrodes being spaced from each other by distances which

are different for the individual color layers.

The first substrate may have a protective layer provided on a surface thereof adjacent the second substrate for preventing elusion of impurities from the color layers.

(Working)

The reason why coloring occurs with a liquid crystal display apparatus of the transverse electric field driven type when the liquid crystal display apparatus is viewed from an oblique direction arises from the fact that, when the factor f defined by the expression (2) varies depending upon whether a ray comes in perpendicularly or from an oblique direction, the manner of the variation is varied by λ.

A color liquid crystal display apparatus of a high quality with which such coloring is called in question employs a color filter in almost all cases.

FIG. 4 is a diagram illustrating an example of transmission factor spectrum characteristics of color filters.

As seen from FIG. 4, the color filters selectively pass certain limited wavelength regions corresponding to the three primary colors of R, G and B therethrough. The peaks of the transmission factor spectra of the color filters illustrated in FIG. 4 are 460 nm for blue, 540 nm for green and 640 nm for red. Further, the wavelength regions having transmission factors higher than 70 % those at the peaks are 420 to 500 nm for blue, 510 to 580 nm for green and 590 or more for red. In those wavelength regions, since 70 % or more of incoming

light passes through the color filters, they have a significant influence on the display characteristic.

Thus, if, taking a radiation spectrum of back light, a spectral luminous efficacy and so forth into consideration, a certain wavelength from within the wavelength regions described above is selected as a representative and examined in regard to the transmission and so forth upon designing, then the values of the transmission factor and so forth for an arbitrary wavelength in the wavelength regions become substantially equal to each other within a range of conversion regarding the transmission factor of the color filter.

Normally, since λ_B = 460 nm, λ_G = 550 nm and λ_R = 610 nm for the blue, green and red color filters, respectively, are positioned substantially at the centers of the respective transmission wavelength regions, they can be selected as the representative values.

Although the following description proceeds using the values mentioned above as representative values, the specific values need not necessarily be used as the representative values.

First, for the selected wavelengths λ_R, λ_G and λ_B, the thicknesses of the liquid crystal layer of pixels corresponding to the color filters are determined so as to satisfy

$$d_R/\lambda_R = d_G/\lambda_G = d_B/\lambda_B \qquad (7)$$

In this instance, the f factors of R, G and B when light

comes in from the front are given by

$$f_R = \sin^2(\pi \cdot \Delta n dR_{eff}/\lambda_R) \qquad (8)$$

$$f_G = \sin^2(\pi \cdot \Delta n dR_{eff}/\lambda_G) \qquad (9)$$

$$f_B = \sin^2(\pi \cdot \Delta n d_{Reff}/\lambda_B) \qquad (10)$$

where the effective thicknesses d_{Reff}, d_{Geff} and d_{Beff} of the liquid crystal layer turned by the transverse electric field and the cell gaps d_R, d_G and d_B have a relationship given by the following expression:

$$d_{Reff}/d_R = d_{Geff}/d_G = d_{Beff}/d_B \qquad (11)$$

Using the expressions (7) to (11),

$$f_R = f_G = f_B \qquad (12)$$

is obtained.

On the other hand, if a substrate is viewed, in a white display condition, obliquely from a direction perpendicular to the directors as seen in FIG. 10, then the refractive index anisotropies Δn felt with the ray do not vary, but only the optical path lengths L increase in accordance with the following expressions:

$$L_R = d_{Reff}/\cos(\theta') \qquad (13)$$

$$L_G = d_{Geff}/\cos(\theta') \qquad (14)$$

$$L_B = d_{Beff}/\cos(\theta') \qquad (15)$$

where θ' is the angle defined between the direction in which the light advances in the liquid crystal and a substrate normal, and strictly speaking, it is different for the individual colors where the refractive index has a wavelength dependency.

However, since this wavelength dependency is very small, it may be handled as being substantially fixed. Where the f factors when light comes in obliquely are represented by f'_R, f'_G and f'_B for R, B and G, respectively, from the definition of f of the expression (2) and the expressions (7), (11), (13), (14) and (15),

$$f'_R = f'_G = f'_B \qquad (16)$$

is obtained. Accordingly, as the inclination angle θ varies, although the values of the factors f themselves vary, since they have quite same values also for different wavelengths, no coloring occurs.

While description is given above of the case wherein the direction in which a substrate is viewed is inclined to a direction perpendicular to the directors of the liquid crystal, since the ratio between the optical path length and the wavelength is fixed in any other direction irrespective of the wavelength, the expression (16) stands in whichever direction the substrate is viewed and no coloring occurs.

This fact can be confirmed quantitatively by a simulation.

FIG. 5 is a diagram illustrating a relationship between the inclination angle and the transmission factor in the active matrix liquid crystal display apparatus of the present invention when light comes in, upon displaying of white, in a direction perpendicular to the liquid crystal directors but oblique to the substrate, and FIG. 6 is a diagram illustrating a relationship between the inclination angle and the

transmission factor in the active matrix liquid crystal display apparatus of the present invention when light comes in, upon displaying of white, in a direction same as the liquid crystal directors but oblique to the substrate. It is to be noted that, in FIGS. 5 and 6, assuming a case wherein white is displayed on a liquid crystal display apparatus wherein the thickness of the liquid crystal layer is varied for the individual colors of the color filters, the relationship between the inclination angle θ of the ray and the transmission factor is obtained by calculation with lights having wavelengths of 610 nm, 550 nm and 460 nm representing the color filters of R, G and B (Red, Green and Blue), and the axis of abscissa represents the inclination angle of the incoming ray from the substrate normal and the axis of ordinate represents the transmission factor normalized with the front transmission factor. Here, the thicknesses of the liquid layer corresponding to R, G and B are 5.0 μm, 4.5 μm and 3.8 μm, respectively, while the intensity of the transverse electric field to be applied is set so as to increase in inverse proportion to the thickness of the liquid crystal layer so that the turning angles of the liquid crystal layer by the transverse electric field may be equal for R, G and B.

The azimuth in which the ray is inclined was taken, in FIG. 5, to a direction perpendicular to the turned liquid crystal directors, but taken, in FIG. 6, to the same direction as the turned liquid crystal directors.

As apparently seen from FIGS. 5 and 6, as the inclination angle θ varies, the transmission factors vary, but they exhibit a same behavior for the wavelengths which represent the respective color filters. Accordingly, it was confirmed successfully also by the simulation that no coloring occurs at all.

When the thickness of the liquid crystal layer is varied for the individual colors of the corresponding color filters, the intensity of the transverse electric field necessary to turn the directors of the liquid crystal by a certain fixed angle increases in inverse proportion to the thickness of the liquid crystal layer. Accordingly, the intensities of the transverse electric fields to be applied in order to obtain a white display make the ratio of 3.8 : 4.5 : 5.0 for R, G and B. Therefore, when the distance between a pixel electrode and an opposing electrode was set to 10 μm, the potential difference between the pixel electrode and the opposing electrode in order to effect white display was 5.5 V for red, 6.0 V for green and 7.0 V for blue.

A system which provides voltages different for the individual colors in this manner increases in complexity of circuitry and invites an increase in cost for a driving system. Therefore, the distance between a pixel electrode and an opposing electrode is made different for the individual colors such that it is 11 μm for red, 10 μm for green and 8.5 μm for blue so that a good white display can be obtained by applying

6 V uniformly to pixels corresponding to all of the colors.

[The embodiments of the invention]

Next, the embodiments of the invention are explained with reference to the drawings.

(First Embodiment)

FIGS. 1(a) and (b) are a sectional view and a plan view, respectively, showing a first embodiment of the active matrix liquid crystal display apparatus of the present invention.

The first embodiment is described with reference to FIGS. 1(a) and (b). Each pixel electrode 3 which forms a pixel is connected to the source electrode of a thin film transistor which has a scanning line 16 as a gate electrode thereof, and the drain electrode of the thin film transistor is connected to a signal line 1. The pixel electrode 3 has a longitudinal direction parallel to the signal line 1 and has an opposing electrode 2 connected by an opposing electrode bus line 17.

A liquid crystal layer 4 is held between two glass substrates 10, and orientation films 23 are disposed on two substrate interfaces and are oriented uniformly in a rubbing direction 24 of Fig 1(b) by rubbing them in the same direction.

A pair of polarizing plates 5 disposed on the outer sides of the two glass substrates 10 have polarization axes perpendicular to each other, and the polarization axis of one of the polarizing plates 5 coincides with the initial orientation direction of the liquid crystal layer 4.

In the liquid crystal display apparatus of the transverse electric field type having the construction described above,

when the potential difference between the pixel electrode 3 and the opposing electrode 2 is 0, black is displayed, and as the potential difference increases, the liquid crystal layer 4 is turned to cause double refraction thereby to raise the transmission factor. When the liquid crystal layer 4 is turned approximately by 45 degrees, the brightness exhibits its highest value.

A color filter is disposed on the opposing substrate and includes color layers 6, 7 and 8 for selectively passing the colors of red, green and blue therethrough, respectively, and a black matrix 9 provided to inhibit leakage of light from any other area than display areas in which effective display control is performed.

For each pixel, the cell thickness of the liquid crystal layer 4 is varied in accordance with the color to be selected by the color filter such that it may be d_R for red, d_G for green and d_B for blue. In this instance, if the wavelength represented by a color of the color filter is se to λ_R for red, λ_G for green and λ_B for blue, then the layer thicknesses of the liquid crystal layer 4 corresponding to the colors are determined so as to satisfy the following expression:

$$d_R/\lambda_R = d_G/\lambda_G = d_B/\lambda_B \qquad (17)$$

FIGS. 3(a) and (b) are a sectional view and a plan view, respectively, showing a second embodiment of the active matrix liquid crystal display apparatus of the present invention;

In order to vary the cell thickness of the liquid crystal layer 4 for the individual colors of the color filter in this manner, such a color filter substrate provided with spacers 26 as shown in FIG. 2(a) and a substrate having a TFT array formed thereon were combined in such a manner as seen in FIG. 2(b), and liquid crystal was filled between the two substrates to form the panel. It is to be noted that the spacers 26 are formed on the black matrix 9 on the opposing substrate corresponding to crossing locations between the scanning lines 16 and the signal lines 1. Consequently, in a condition wherein the two substrates are combined in such a manner as shown in FIG. 2(b), the spacers 26 has such spacer contacting portions 14 as shown in FIG. 1(b).

In the thickness of the liquid crystal layer 4, while the transmission factors for the individual color layers of the color filter are kept equal to those of ordinary color filters which have such transmission factor characteristics as shown in FIG. 4, only the film thicknesses of the color layers were made different so as to satisfy the expression (20). Here, where the height of the spacers 26 is represented by t_S, the thickness of the black matrix 9 is represented by t_M and the thicknesses of the scanning lines 16 and the signal lines 1 are represented by t_V and t_H, respectively, the film thicknesses t_R, t_G and t_B of the color layers of R, G and B were controlled so as to satisfy

$$t_S + t_M + t_V + t_H = t_R + d_R = t_G + d_G = t_B + d_B \quad (18)$$

In this instance, the concentration of a pigment to be

dispersed into each color layer is adjusted in accordance with the film thickness of the color layer.

It is also possible to form an overcoat layer on the color filter shown in FIG. 2(a) as seen in FIG. 2(c) in order to prevent elusion of impurities from the color layers.

Further, in order to dispose the two substrates parallelly in a spaced relationship by a fixed distance from each other, granular spacers 25 sprayed uniformly as seen in FIG. 12(d) may be used in place of the spacers of the color filter with a spacer.

Further, while, in the present embodiment, the spacers 26 are provided at the crossing points between the scanning lines 16 and the signal lines 1, they need not necessarily be provided at those locations, but if the substrates can be held in a fixedly spaced relationship from each other, the spacers may be provided in any location in pixels. Preferably, however, the spacers 26 are provided at locations which doe not have an influence on a display and at which they are covered with the black matrix 9. In this instance, since the thickness of the liquid crystal layer formed with the spacers 26 is varied a little by the pattern of wiring lines or an insulation film, designing of the height of the spacers 26 based on such variation is required.

(Second Embodiment)

FIGS. 3(a)and(b) are a sectional view and a plan view, respectively, showing a second embodiment of the active matrix liquid crystal display apparatus of the present invention.

As shown in FIGS. 3(a) and (b), the present embodiment is quite same as the first embodiment except that the distance between a pixel electrode 3 and an opposing electrode 2 is different between a pixel 20 corresponding to green and a pixel 21 corresponding to blue and that numerical aperture adjustment portions 22 are present.

Since the distance between a pixel electrode 3 and an opposing electrode 2 is made different as seen in FIGS. 3(a) and (b), it can be realized by applying the same potential that the transverse electric field intensity necessary to turn the liquid crystal layer 4 is different among the different colors, which arises from a variation of the thickness of the liquid crystal layer 4. Consequently, driving is facilitated.

Further, the numerical aperture adjustment portion 22 is provided in order to prevent the ratio of an effective display area held between a pixel electrode 3 and an opposing electrode 2 occupied in one pixel, that is, the numerical aperture, from varying the distance between the pixel electrode 3 and the opposing electrode 2 by an opaque metal layer formed as the same layer as the opposing electrode 2 or the same layer as the pixel electrode 3. Since the distance between a pixel electrode 3 and an opposing electrode 2 is largest with a pixel 19 corresponding to red and decreases in order of green and blue, the area of the numerical aperture adjustment portion 22 is largest with a pixel 19 corresponding to red, but is rather small with another pixel 20 corresponding to green,

and no numerical aperture adjustment portion 22 is provided for a pixel 21 corresponding to blue.

The other construction is quite same as that of the first embodiment.

(Working example)

In the following, a working example of the embodiments described above are described in detail using detailed values including a method of producing the same.

First, a method of producing an active matrix substrate which is the second substrate is described.

As a metal layer from which signal lines 1, opposing electrodes 2 and opposing electrode bus lines 17 are to be formed, a Cr film is deposited with 150 nm on a transparent glass substrate 10 and patterned.

Then, as a gate insulating film 11, a silicon nitride film of 400 nm thick, a non-doped amorphous silicon film of 350 nm thick and an n-type amorphous silicon film of 30 nm thick are successively deposited.

Then, an n-type amorphous silicon film and a non-doped amorphous silicon layer are formed in accordance with the pattern of island-shaped amorphous silicon 18.

Then, as a metal layer from which signal lines 1 and pixel electrodes 3 are to be formed, a Cr film is deposited with the thickness of 150 nm and patterned.

Then, a protective insulating film 12 is formed, and the protective insulating film 12 is removed at peripheral terminal locations thereof to complete a TFT array. In this

instance, the patterns of the pixel electrodes 3 and the opposing electrodes 2 are formed such that the distances between them may be fixed to 10 μm with pixels corresponding to all colors as seen in FIGS. 1(a) and (b).

Now, a method of producing a color filter substrate as the first substrate is described.

Photosensitive polymer of 0.1 μm thick containing carbon is formed on a transparent glass substrate and a black matrix layer 9 is provided using a photo-lithography technique.

Then, photosensitive polymer containing a red pigment is formed on the substrate, and the photosensitive polymer formed in a region other than the region in which the red filter is formed is removed by a photo-lithography technique to form the red filter 6.

Then, similar steps are performed to successively form the green filter 7 and the blue filter 8.

The color filter produced in this manner had such transmission factor spectra as illustrated in FIG. 4.

Next, a method of forming the spacers is described.

FIG. 7 is a view showing an example of a construction of the spacers provided in the active matrix liquid crystal display apparatus of the present invention.

As seen in FIG. 7, each spacer 26 is formed in a manner wherein all color layers are layered. Where a spacer 26 is formed in this manner, the height t_s of the spacer is given by

$$t_S = t_R + t_G + t_B \quad (19)$$

Where, taking the fact that the thicknesses of scanning lines 16 and signal lines 1 are 0.15 μm and the relationship given by the expression (18) into consideration, the thicknesses t_R, t_G and t_B of the color layers for R, G and B were set to 0.96 μm, 1.45 μm and 2.15 μm, respectively, the thicknesses of the liquid crystal layer 4 at pixels for the individual colors were 5.0 μm for red, 4.5 μm for green and 3.8 μm for blue.

The thicknesses of the liquid crystal layer 4 mentioned above provide, where λ_B = 460 nm, λ_G = 550 nm and λ_R = 610 nm are selected as wavelengths for representations of the color filters from the transmission factor spectra of the color filter shown in FIG. 4, an equal ratio between the wavelength and the thickness of the liquid crystal layer for the individual colors of the color filter.

On the color filter produced in this manner, an overcoat layer 13 was formed with the thickness of 0.1 μm.

Orientation films 23 are applied to both of the active matrix substrate and the color filter substrate produced in such a manner as described above and then rubbed in the rubbing direction 24 shown in FIG. 1. Then, the two substrates are adhered to each other and secured at peripheries thereof to each other with a seal material, and then liquid crystal is injected into and encapsulated in a space between the substrates to form a liquid crystal panel.

In the liquid crystal panel produced in such a manner as described above, since the ratios between the wavelengths representing the color filter and the thicknesses of the liquid layer are substantially equal for the individual colors of the color filter, the principle described hereinabove applies to this liquid crystal panel, and consequently, a good display characteristic free from coloring can be obtained.

While, in the working example described above, the overcoat layer is provided on the color filter, it need not particularly be provided if the stability of the color layers is sufficiently high.

Further, while, in the working example described above, the spacers 26 are formed by laying color layers of the color filter, a different layer may alternatively be formed to form the spacers 26 using a photo-lithographic technique. Further, the two techniques may be combined to form the spacers 26 by layering the color layers and the different layer.

Further, the spacers 26 need not be provided on the color filter, but as shown in FIG. 2(d), a granular spacer may be sprayed, upon combination of liquid crystal, to control the thickness of the liquid crystal layer.

Furthermore, while, in the working example described above, the thickness of the liquid crystal layer is varied corresponding to the individual colors by making the thicknesses of the color layers of the color filter different from each other, the thicknesses of the liquid crystal layer corresponding to the individual colors may be controlled by

layering dielectric layers different from the color layers on the individual layers while varying the thicknesses of the dielectric layers as seen in FIG. 8.

FIG. 8 is a view showing a further embodiment of the active matrix liquid crystal display apparatus of the present invention.

Further, by using the same production procedure while varying the shapes of the patterns of pixel electrodes 3 and opposing electrodes 2 in such a manner as seen in FIG. 3, a liquid crystal display panel formed from the second embodiment was obtained.

In this instance, the distance between a pixel electrode 3 and an opposing electrode 2 was set to 11μm for pixels corresponding to red, 10μm for pixels corresponding to green and 8.5μm for pixels corresponding to blue. Further, in order to prevent the area of a display region held between a pixel electrode 3 and an opposing electrode 2 from being varied for the individual colors, numerical aperture adjustment portions 22 were provided for pixels 19 corresponding to red and pixels 20 corresponding to green. Consequently, while the difference between a pixel potential and an opposing potential necessary to obtain the highest brightness was different, in the working example of the first embodiment, for the individual colors, in a working example of the second embodiment, by application of 6.0V, the highest brightness was obtained with pixels corresponding to all of

the colors. Besides, since the equal numerical aperture was obtained for all of the colors without the necessity for a special countermeasure in structure, a good white characteristic was obtained successfully.

[Effect of the invention]

Since the present invention is constructed in such a manner as described above, it exhibits the following effects.

In the active matrix liquid crystal display apparatus as set forth in claims 1 and 2, since the liquid crystal layer has a thickness which varies depending upon transmission wavelengths of the color layers, the active matrix liquid crystal display apparatus can provide a very good display free from any coloring from whichever direction it is viewed.

In the active matrix liquid crystal display apparatus set forth in claim 3, since the distance between a pixel electrode and an opposing electrode is set different for the individual color layers, an equal voltage can be applied to the pixel electrodes corresponding to the individual color layers to achieve the effect described above, and consequently, driving is facilitated.

In the active matrix liquid crystal display apparatus set forth in claim 4, since the protective layer is provided on the surface of the first substrate adjacent the second substrate, elusion of impurities from the color layers can be prevented.

BRIEF EXPLANATION OF THE DRAWINGS

FIGS. 1(a) and (b) are a sectional view and a plan view, respectively, showing a first embodiment of the active matrix liquid crystal display apparatus of the present invention.

FIGS. 2(a) to (d) are views illustrating a method of controlling the liquid crystal layer thickness, and wherein (a) is a sectional view of a color filter provided with a spacer, (b) is a view showing the color filter combined with an active matrix substrate, (c) is a sectional view where an overcoat layer is provided, and (d) is a view where a granular spacer is provided.

FIGS. 3(a) and (b) are a sectional view and a plan view, respectively, showing a second embodiment of the active matrix liquid crystal display apparatus of the present invention;

FIG. 4 is a diagram illustrating an example of transmission factor spectrum characteristics of color filters.

FIG. 5 is a diagram illustrating a relationship between the inclination angle and the transmission factor when light comes into the active matrix liquid crystal display apparatus of the present invention, upon displaying of white, from a direction perpendicular to the liquid crystal directors and oblique to a substrate.

FIG. 6 is a diagram illustrating a relationship between the inclination angle and the transmission factor when light comes into the active matrix liquid crystal display apparatus of the present invention, upon displaying of white, from a direction same as that of the liquid crystal directors and

oblique to a substrate.

FIG. 7 is a view showing an example of a construction of a spacer provided in the active matrix liquid crystal display apparatus of the present invention.

FIG. 8 is a view showing a third embodiment of the active matrix liquid crystal display apparatus of the present invention.

FIG. 9 is a view showing a liquid crystal display system of the transverse electric field driven type which exhibits a good display characteristic.

FIGS. 10(a) and (b) are diagrammatic views illustrating passage of light through liquid crystal when the light comes in obliquely, and wherein (a) is a view as viewed from an oblique direction to a substrate and (b) is a view as viewed in a direction parallel to the substrate.

FIG. 11 is a diagram illustrating a relationship between the inclination angle and the transmission factor when light comes in, when white is to be displayed, in a direction perpendicular to the liquid crystal directors and oblique to the substrate.

FIG. 12 is a diagram illustrating a relationship between the inclination angle and the transmission factor when light comes in, when white is to be displayed, in a direction same as that of the liquid crystal directors and oblique to the substrate.

(The explanation of the signs)

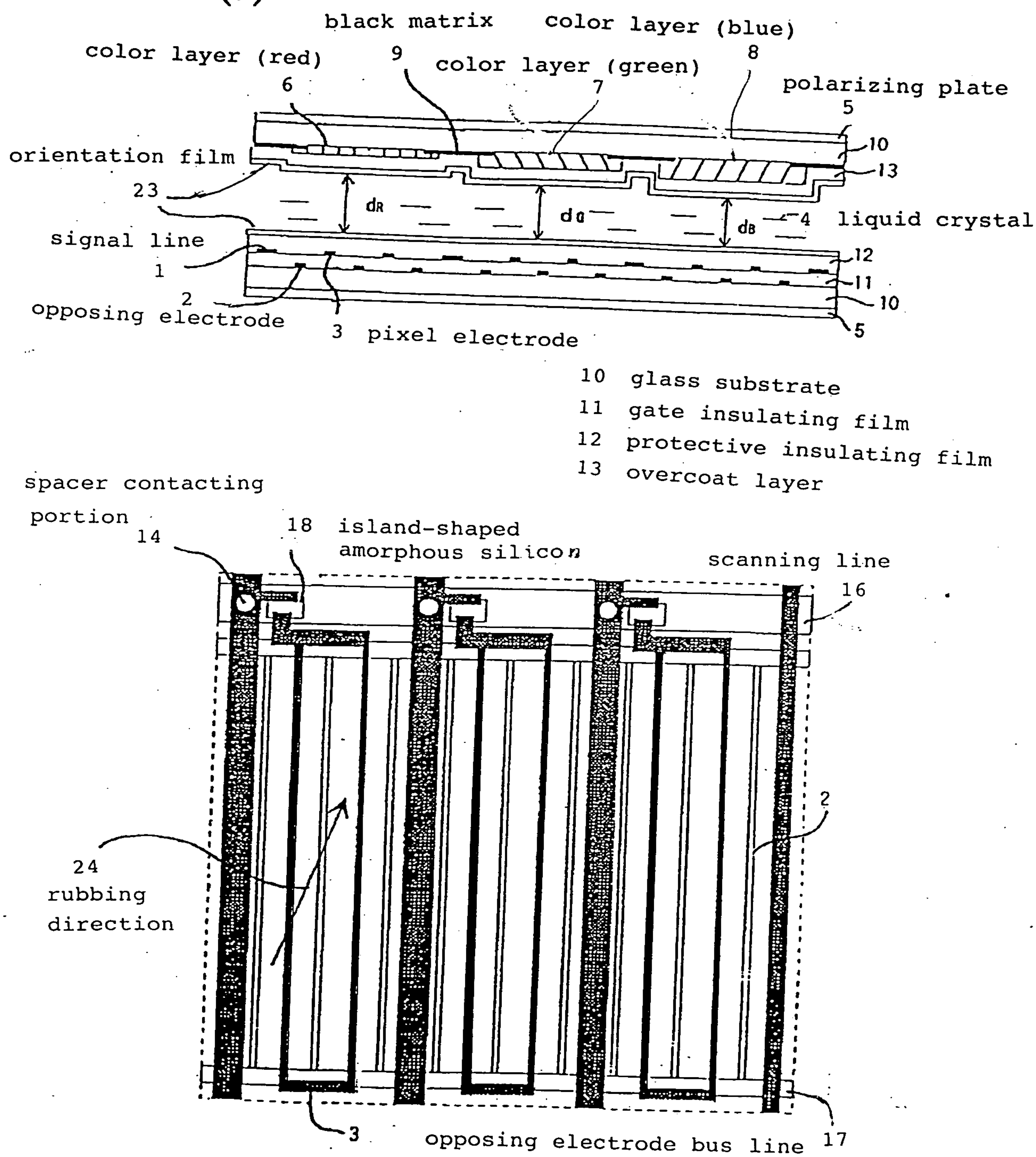
1 signal line

2 opposing electrode

3 pixel electrode
4 liquid crystal
5 polarizing plate
6 color layer (red)
7 color layer (green)
8 color layer (blue)
9 black matrix
10 glass substrate
11 gate insulating film
12 protective insulating film
13 overcoat layer
14 spacer contacting portion
15 dielectric layer
16 scanning line
17 opposing electrode bus line
18 island-shaped amorphous silicon
19 pixel corresponding to red
20 pixel corresponding to green
21 pixel corresponding to blue
22 numeral aperture adjustment portion
23 orientation film
24 rubbing direction
25 granular spacer
26 spacer

A

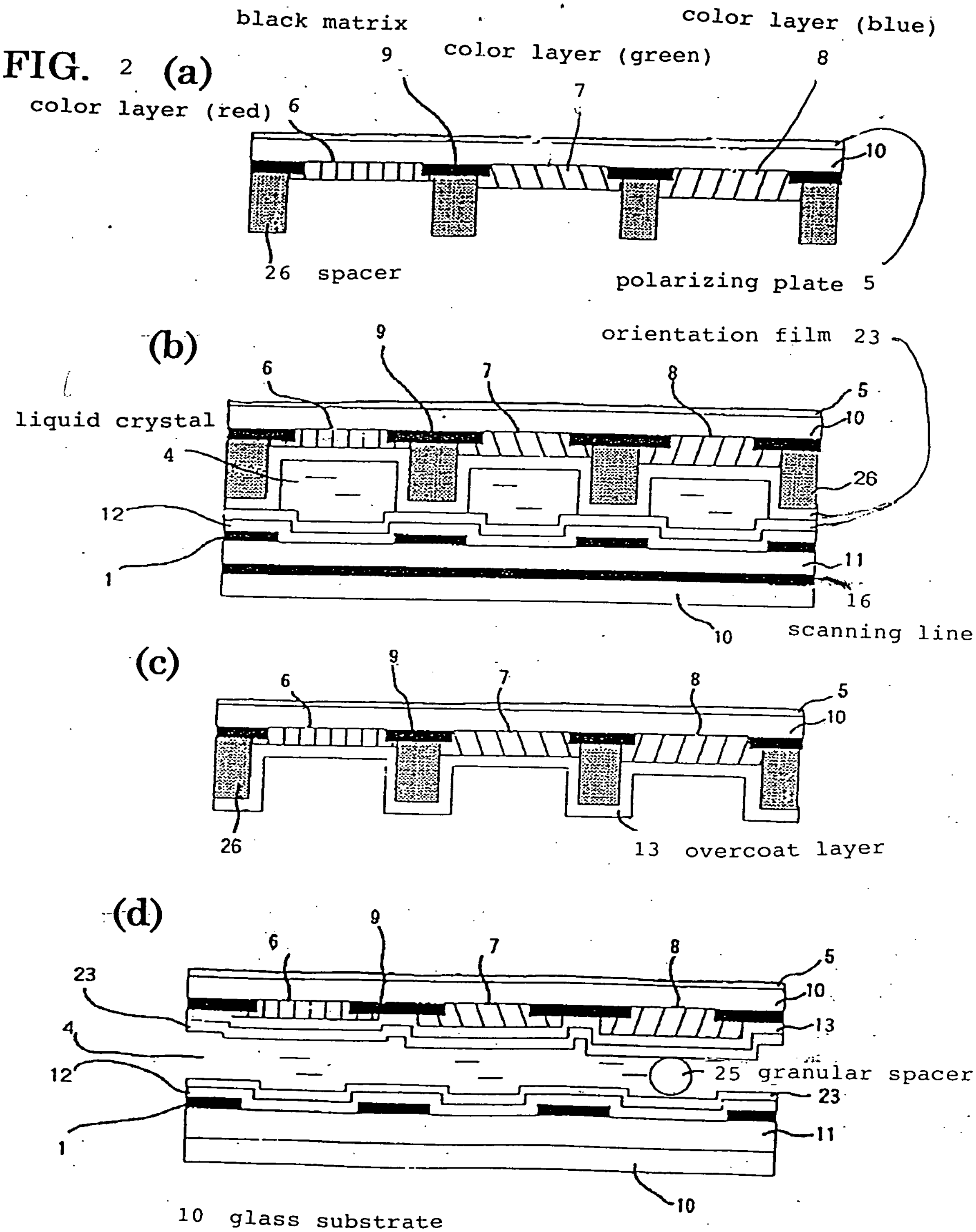
FIG. 1 (a)


black matrix
color layer (blue)
color layer (red)
9
8
color layer (green)
6
7
polarizing plate
5
10
orientation film
13
23
dR
dG
dB
4
liquid crystal
signal line
12
1
11
10
2
opposing electrode
5
3
pixel electrode
10 glass substrate
11 gate insulating film
12 protective insulating film
13 overcoat layer
spacer contacting
portion
14
18
island-shaped
amorphous silicon
scanning line
16
2
24
rubbing
direction
3
opposing electrode bus line
17

(b)

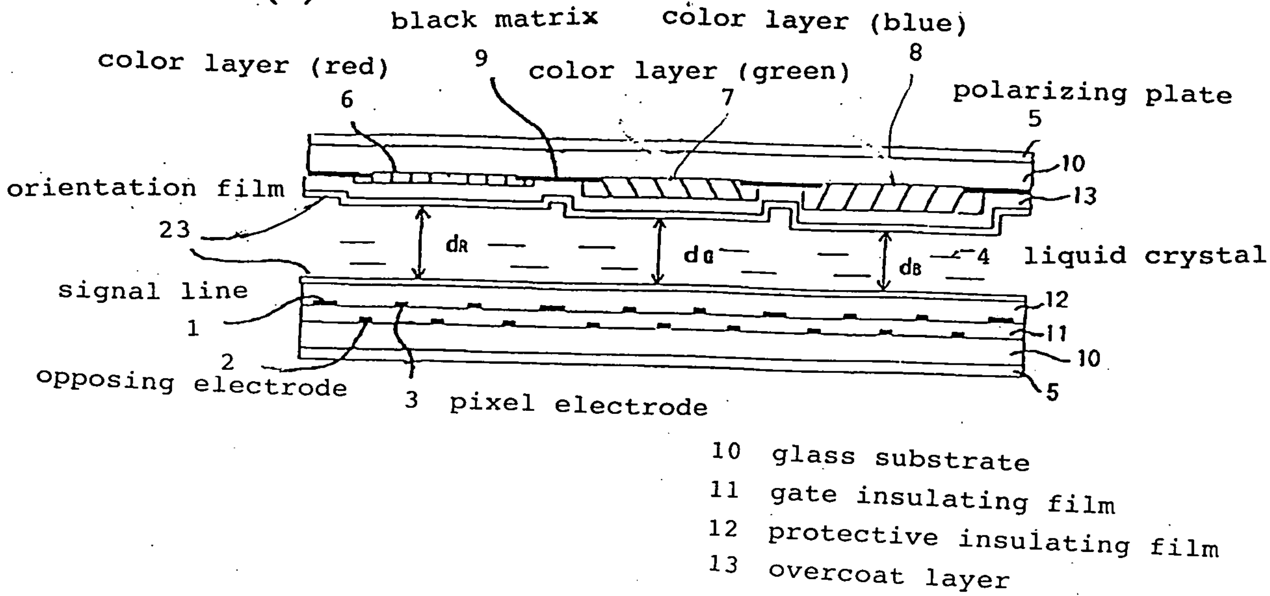
A

FIG. 2



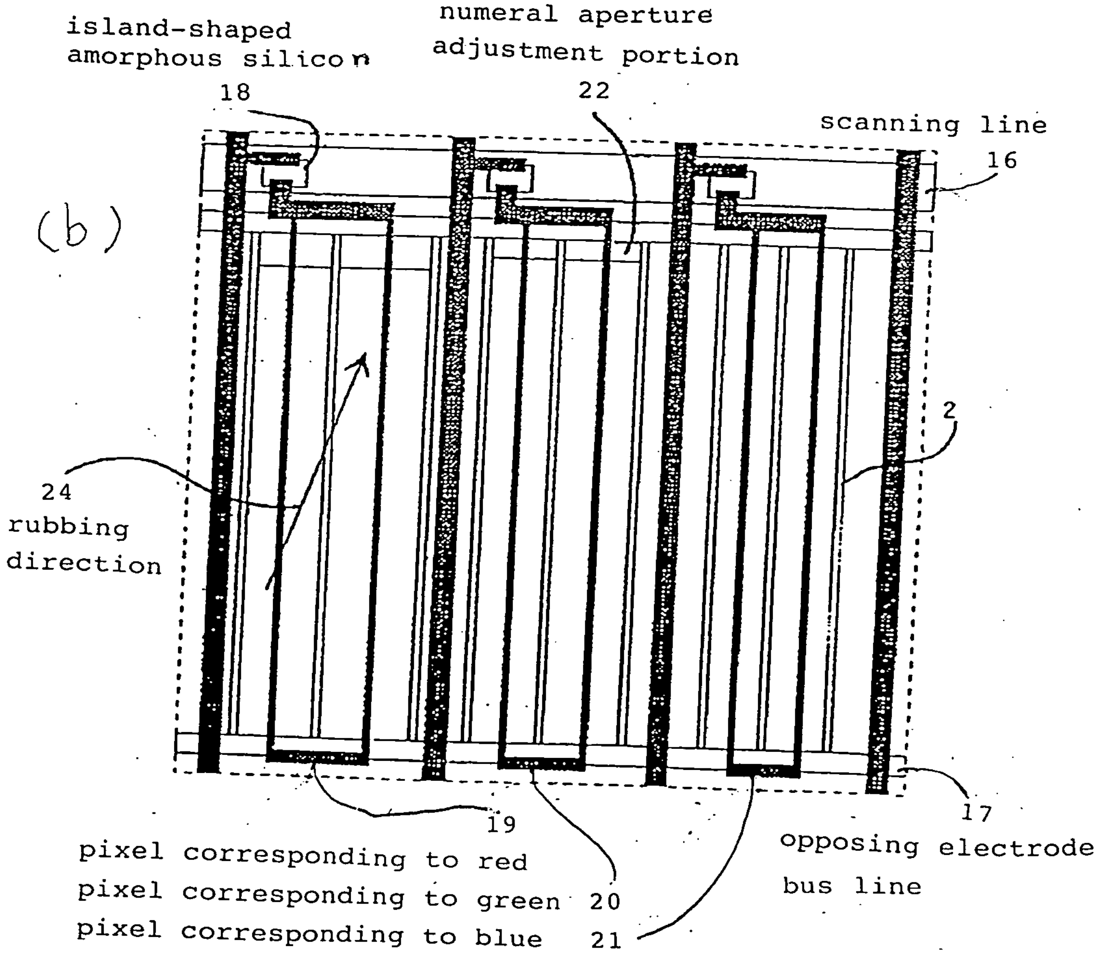
10 glass substrate
11 gate insulating film
12 protective insulating film

FIG. 3 (a)



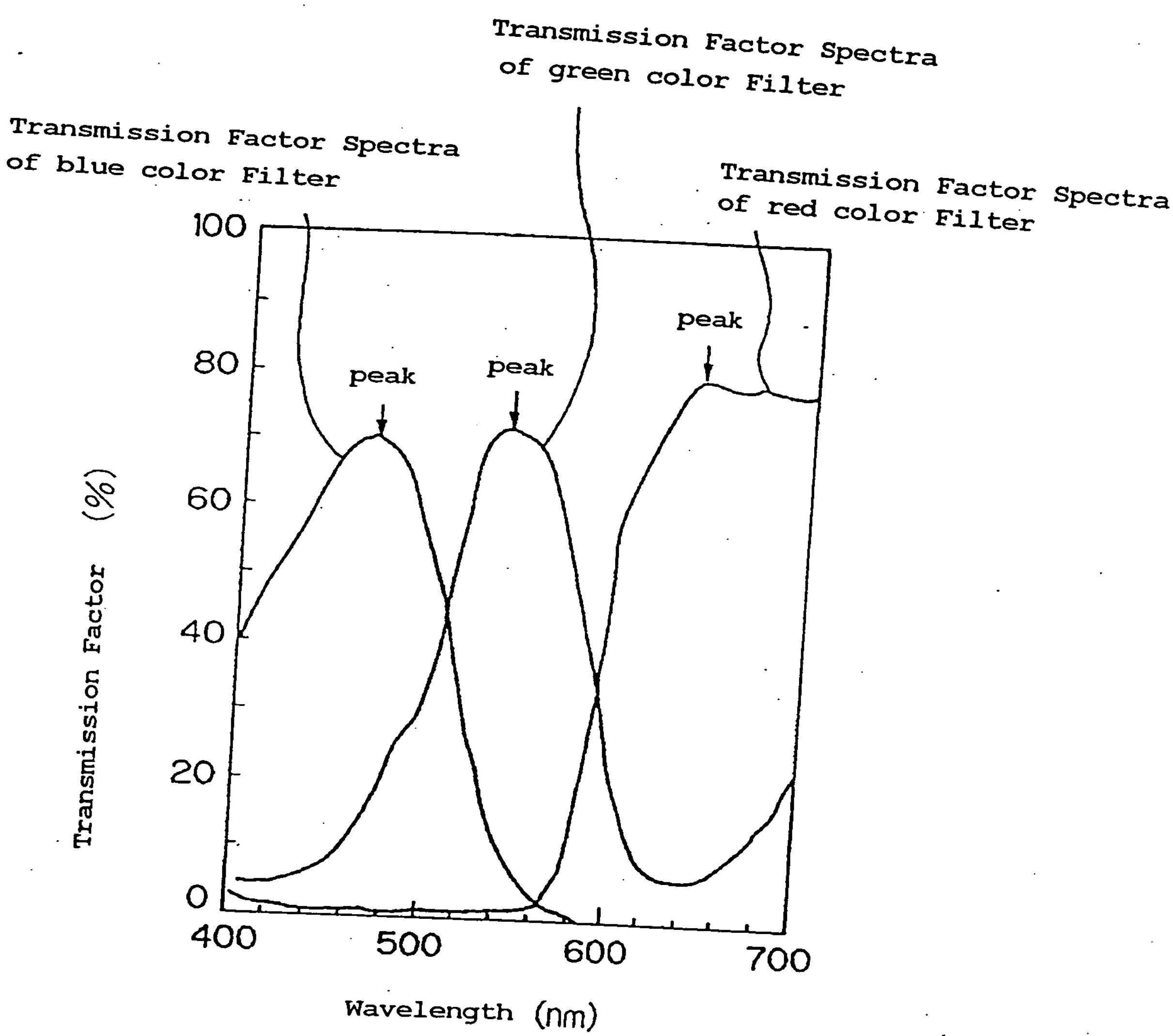
black matrix
color layer (blue)
color layer (red)
9
color layer (green)
8
6
7
polarizing plate
5
10
orientation film
13
23
dR
dG
dB
4
liquid crystal
signal line
12
1
11
2
10
opposing electrode
3
pixel electrode
5
10 glass substrate
11 gate insulating film
12 protective insulating film
13 overcoat layer

(b)



island-shaped amorphous silicon
18
numeral aperture adjustment portion
22
scanning line
16
2
24 rubbing direction
19
17
pixel corresponding to red
pixel corresponding to green 20
pixel corresponding to blue 21
opposing electrode bus line

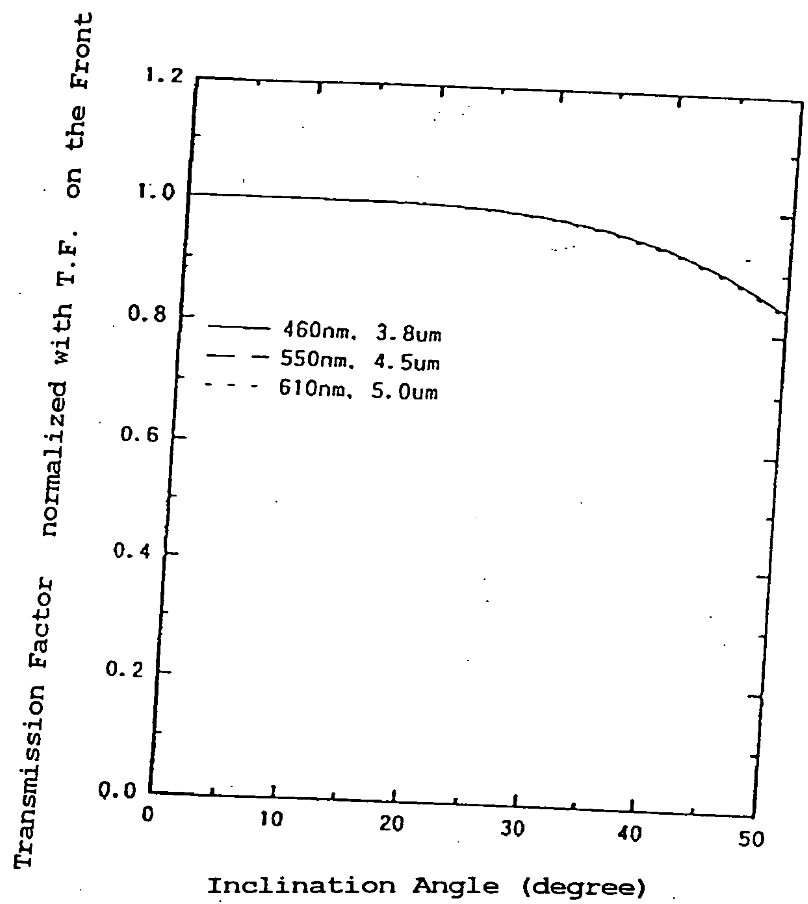
FIG. 4



Transmission Factor Spectra of green color Filter
Transmission Factor Spectra of blue color Filter
Transmission Factor Spectra of red color Filter
peak
peak
peak
100
80
60
40
20
0
400
500
600
700
Transmission Factor (%)
Wavelength (nm)

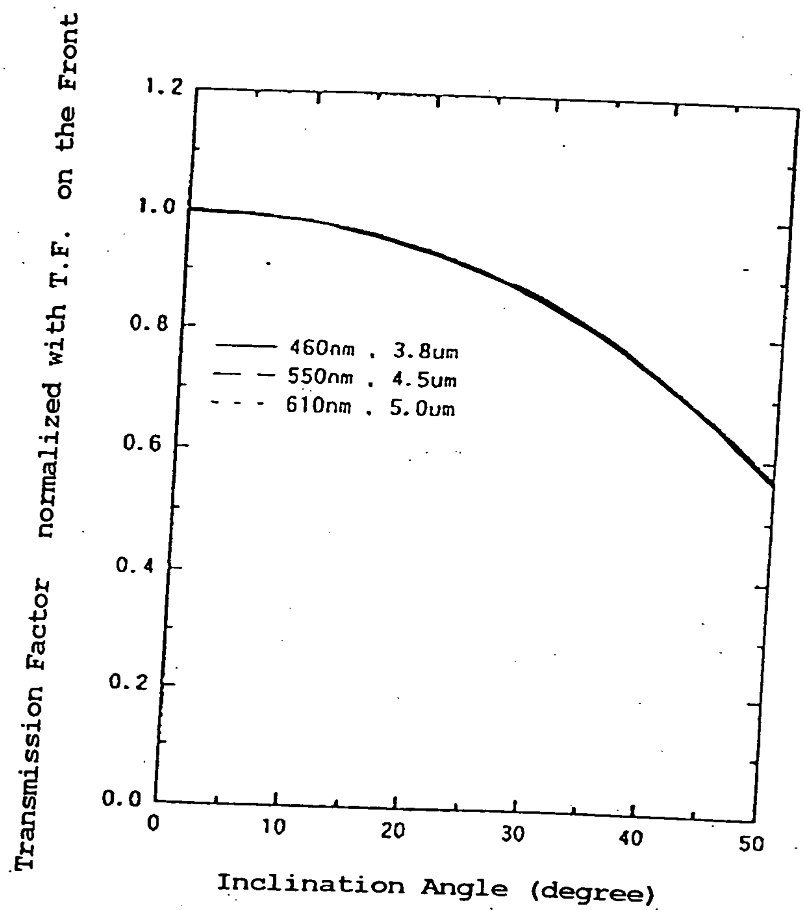
A

FIG. 5



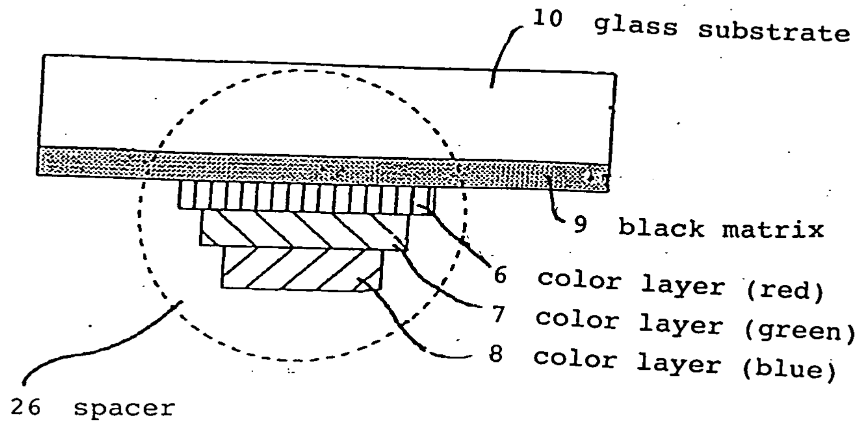
Transmission Factor normalized with T.F. on the Front
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
460nm, 3.8um
550nm, 4.5um
610nm, 5.0um
Inclination Angle (degree)

FIG. 6


Transmission Factor normalized with T.F. on the Front
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
460nm . 3.8um
550nm . 4.5um
610nm . 5.0um
Inclination Angle (degree)

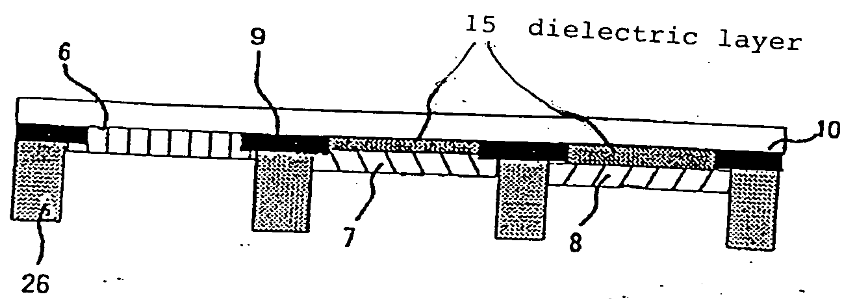
A

FIG. 7



10 glass substrate
9 black matrix
6 color layer (red)
7 color layer (green)
8 color layer (blue)
26 spacer

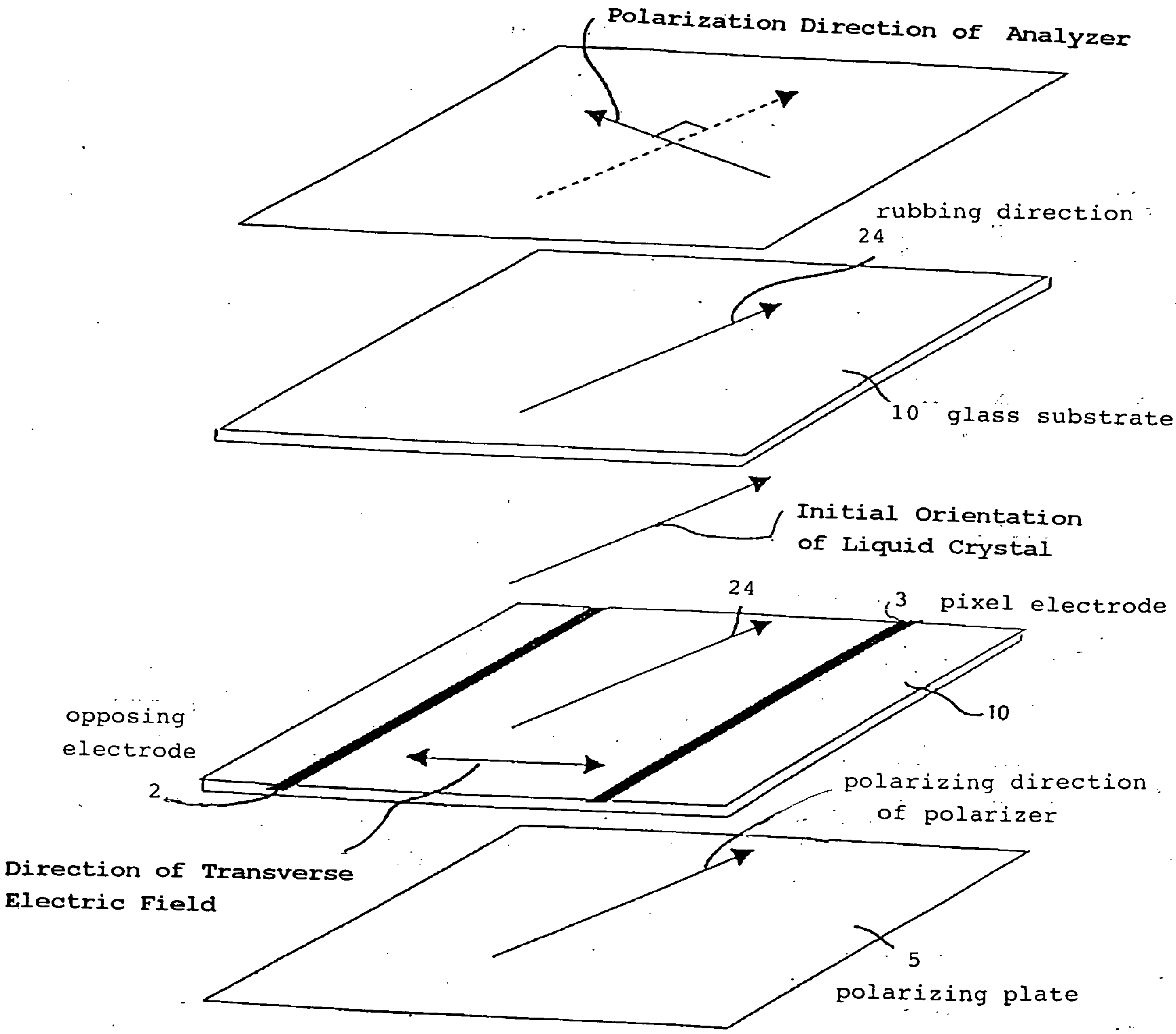
FIG. 8



15 dielectric layer
6
9
10
7
8
26

FIG. 9 PRIOR ART

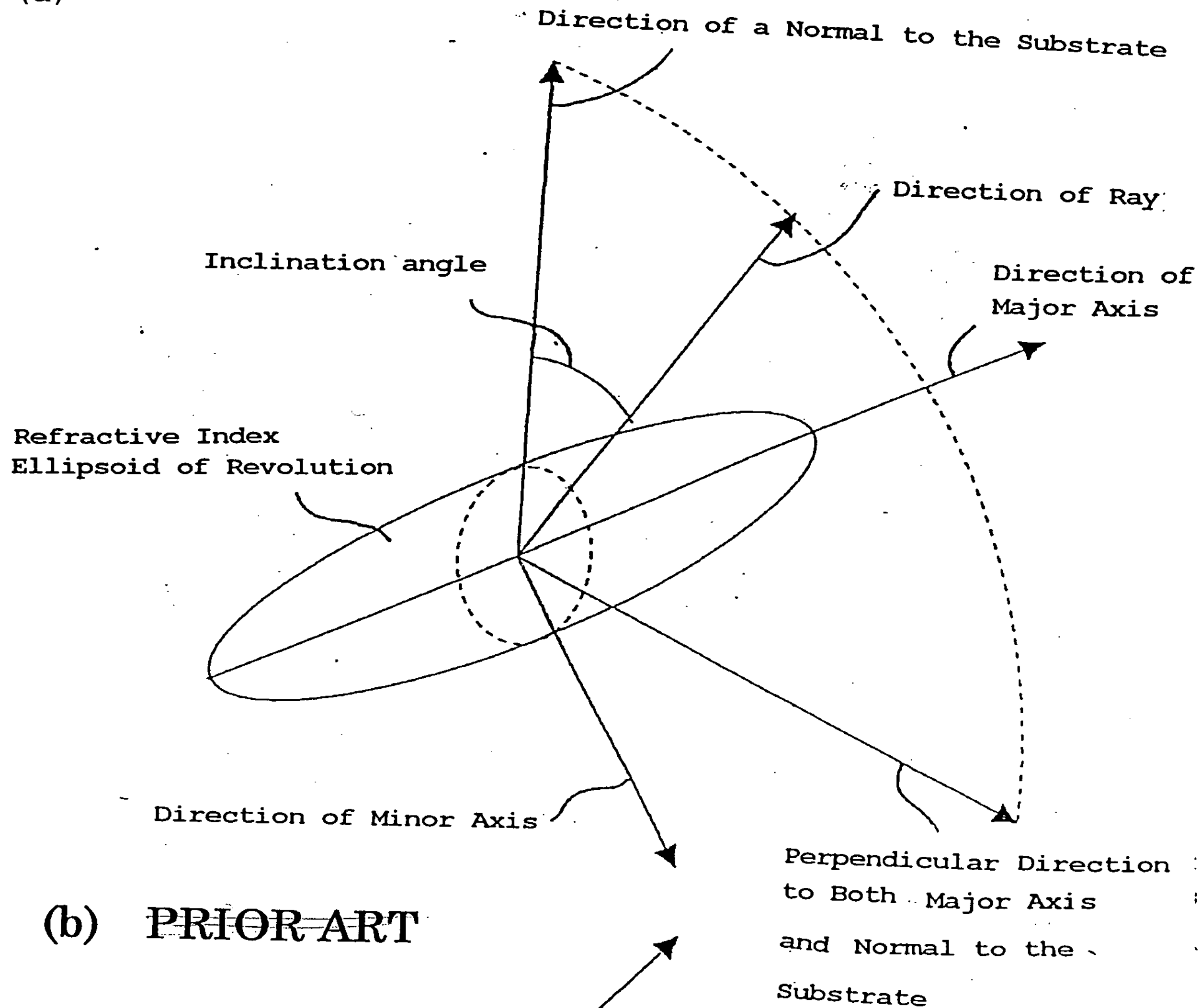
A



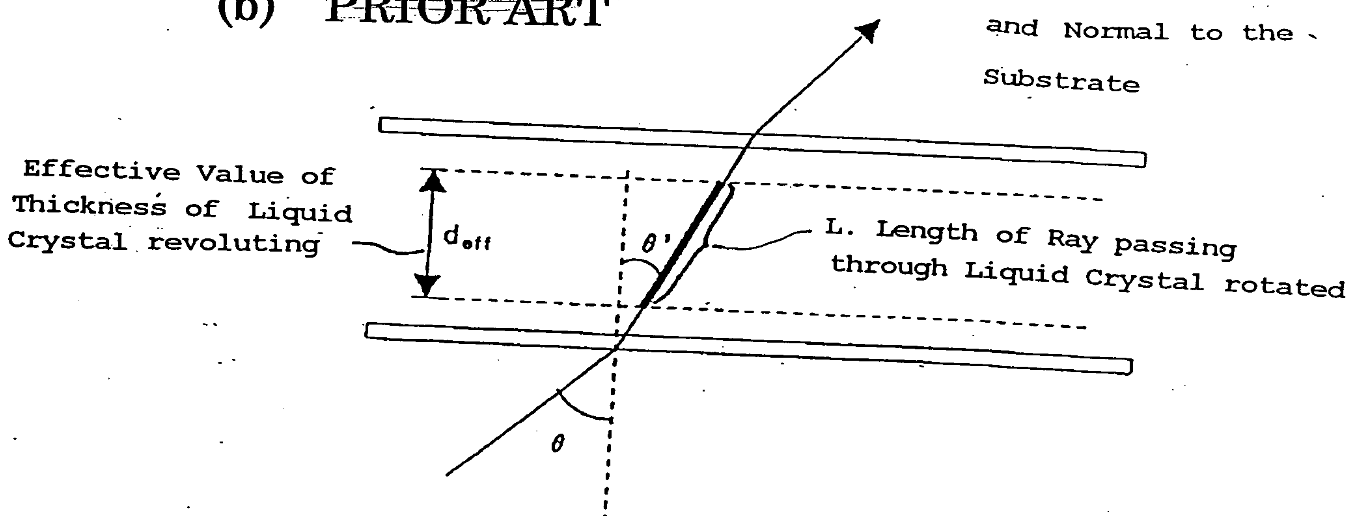
A

FIG. 10 PRIOR ART

(a)

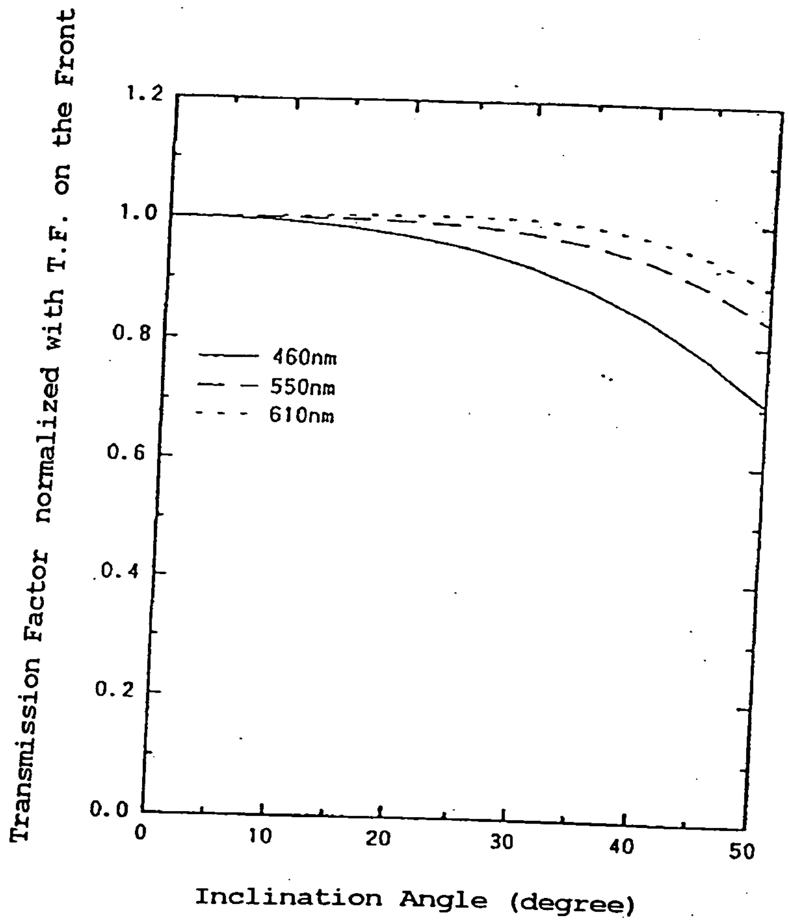


(b) PRIOR ART



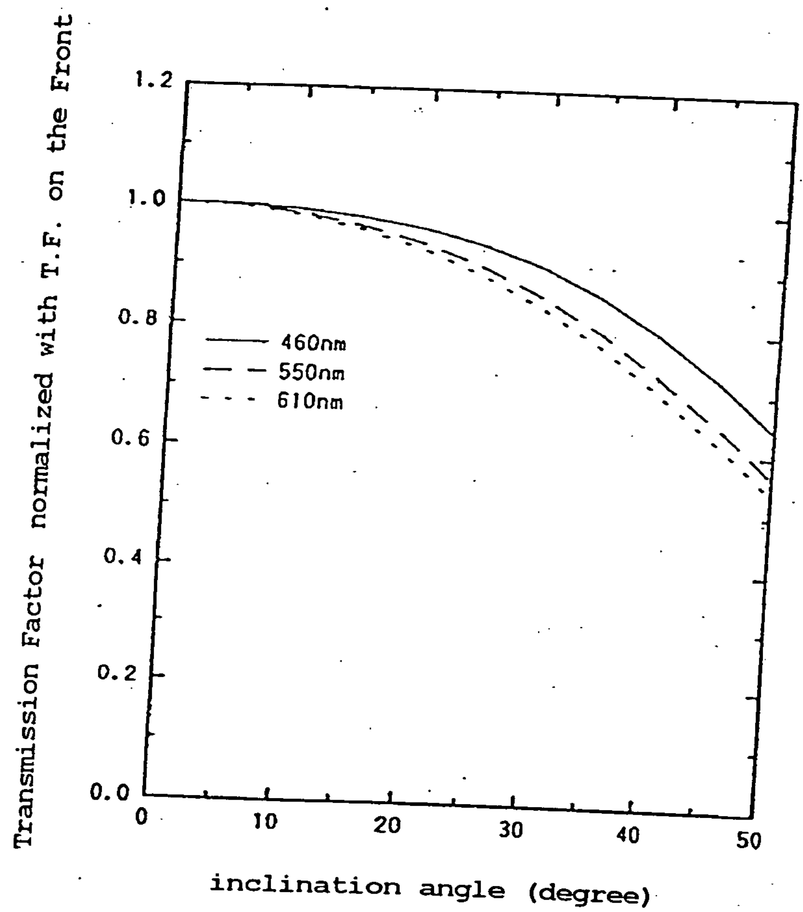
A

FIG. 11 PRIOR ART



A

FIG. 12 PRIOR ART



ABSTRACT OF THE DISCLOSURE

[Problem] On the case of the view from oblique direction with respect to substrate, phenomena of significant coloring occur, according to the watching direction. Thereby ,when image data such as photograph is treated, image of original picture is greatly injured.

[Means for solving] A liquid crystal layer 4 is formed such that the thickness thereof varies in accordance with transmission wavelengths of color layers 6, 7 and 8 so that a very good display which does not exhibit any coloring in whichever direction it is viewed may be obtained.

[Selected drawing] FIG.1

List of drawing numerals of between three applications for contrasting above numerals

A : Japanese Patent Application No. 08-286642

B : Japanese Patent Application No. 09-029032

C : U.S. Patent Application No. 08/960,224

P. A. : Prior Art

A	C	
1	11	
2	12	
3	13	
4	14	
5	15	
6	16	
7	17	
8	18	
9	1	P. A.
10	2	P. A.
11	3	P. A.
12	4	P. A.

B	C	
1	19	
2	20	
3	21	
4	22	
5	23	
6	10	P. A.
7	24	
8	25	
9	26	
10	27	
11	5	P. A.
12	6	P. A.
13	7	P. A.
14	8	P. A.
15	9	P. A.